Normative Blood Pressure and Heart Rate in Pediatric Spinal Cord Injury

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Background: Cardiovascular measures in children with spinal cord injury (SCI) may vary depending on the child's age and physical development in addition to injury-related factors. Developmental changes should be considered when addressing cardiovascular complications in this population. **Objectives:** To determine baseline blood pressure (BP) and heart rate (HR) measurements in youth with SCI, and to investigate differences in BP and HR in relation to age, gender, body mass index (BMI), and injury-related factors. **Methods:** Retrospective chart review was conducted for youth under 19 years who had been admitted for rehabilitation at 1 of 2 pediatric SCI programs. Systolic (SBP) and diastolic (DBP) blood pressures and HR were collected in the morning and afternoon on 3 consecutive days. Mean SBP, DBP, and HR were compared among 4 age groups (0-5 years, 6-12 years, 13-15 years, and 16-18 years) and by gender. Diurnal variations were determined according to level and severity of injury. Associations with BMI and injury-related factors were examined. Charts of 315 youths were reviewed: mean age was 12.3 years, 59% were male, 75% were Caucasian, 62% had complete injury, and 66% had paraplegia. **Results:** With increasing age, SBP and DBP increased and HR decreased. SBP and DBP were positively correlated with BMI. SBP was higher in males, those with incomplete injury, and those with paraplegia. HR was higher in females. There was no association between cardiovascular measures and injury duration. **Conclusion:** BP and HR are a function of age, BMI, and completeness and level of injury in youth with SCI. Awareness of baseline measures will allow for more effective management of cardiovascular complications, especially in youth presenting with atypical symptoms. **Key words:** *blood pressure, development, heart rate, pediatric spinal cord injury*

Individuals who have sustained a spinal cord injury (SCI) are at risk of cardiovascular dysfunction as a result of the interruption in the autonomic nervous pathways, leading to complications such as orthostatic hypotension (OH) and autonomic dysreflexia (AD).[1-3] As the main sympathetic outflow originates from the first thoracic to the upper lumbar segments, the cardiovascular changes are more prevalent in those with cervical and high thoracic level injuries. Both OH and AD manifest as sudden changes in blood pressure (BP) and heart rate (HR), which can cause a range of symptoms that may lead to limitations in activities of daily living or serious medical and neurological consequences. Initially following injury, the loss of supraspinal control of the sympathetic nervous system leads to decreased resting BP and HR. With the subsequent development of peripheral adrenoreceptor hypersensitivity and restoration of the preganglionic sympathetic neurons, BPs may gradually increase to approach normal levels.[1,4,5] In addition to the absolute changes in BP and HR measurements, loss of sympathetic input is also associated with diminished diurnal variation in BP.[1,6] These changes, however, vary depending on the level and severity of injury. Those sustaining complete high cervical level injuries may experience persistent hypotension and loss of diurnal variation, both associated with decreased levels of circulating norepinephrine levels.[2,7] In addition, those with complete or incomplete cervical and high thoracic injuries may present with frequent episodes of AD in the setting of increased sympathetic hyper-responsiveness and diminished descending inhibitory input. Such individual variation of cardiovascular changes in SCI warrants the awareness of baseline BP and HR for prompt recognition and management of autonomic complications.

Compared to the vast literature available about cardiovascular changes occurring after SCI in

Top Spinal Cord Inj Rehabil 2013;19(2):87–95
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www.thomasland.com

doi: 10.1310/sci1902-87

adults, there is little reported for the pediatric SCI population. Developing children generally have lower values for BP and higher mean HRs compared to adults.[8] Physiologic changes in BP and HR accompany growth and development in healthy children, and adult levels are usually reached in adolescence.[9,10] The normative values of BP and HR, however, cannot be applied to children and adolescents with SCI because their autonomic regulatory function has been altered by the injury. In addition, youth with SCI are less physically active and thus undergo changes in body composition, which can affect exercise tolerance and cardiovascular function.[11,12] Many youth are also challenged by numerous medical and neurological complications that require multiple medications, which in turn may have potential side effects on the cardiovascular system.[13-15]

AD in the pediatric SCI population is diagnosed by a sudden elevation in BP above baseline of 15 mm Hg, in addition to signs and symptoms such as headache, facial flushing, and excessive sweating.[16] The prevalence of AD in the pediatric population has been reported to be 40% to 51% among those with injury levels at or above T6.[17,18] This may be an underestimation of AD occurrence, however, as children may have difficulty communicating their discomfort (eg, headache) during an episode, present with atypical symptoms and signs of AD, or present without symptoms.[19] Therefore, it is imperative to be aware of the normative values of BP and HR in youth with SCI to promptly detect and effectively manage potential cardiovascular complications in this population.

The objectives of this study were to determine normative BP and HR measurements in children and adolescents with SCI and to determine differences in BP and HR as a function of age, gender, anthropometric measures, and SCI-related factors. It was hypothesized that in youth with SCI (1) baseline BP will increase and HR will decrease with increasing age, (2) baseline BP will increase with increasing body mass index (BMI), (3) baseline BP and HR will be lower in those with tetraplegia or complete injury compared to those with paraplegia or incomplete injury, and (4) baseline BP and HR will increase with increasing duration of injury.

Methods

Data collection

A retrospective chart review was conducted. Those eligible for inclusion were youth from birth to 18 years who had been admitted for rehabilitation training for at least 5 consecutive days at 1 of 2 pediatric SCI centers in the United States. Youth were excluded from the study if they had undergone surgery within 2 weeks prior to admission, were experiencing fever or other active signs of infection/inflammation, or had documented renal, thyroid, or cardiac disorders. Morning (8:00-9:30 a.m.) and late afternoon (4:00-5:30 p.m.) measurements of systolic and diastolic BP (mmHg) and HR (beats/min) that were obtained as part of routine care were collected over 3 consecutive days. All measurements were taken in the inpatient unit by nurses experienced in obtaining BP and HR; however, specific patient position was not documented in the medical records. If there was a discrepancy of any BP measurement greater than 15 mm Hg within the 3-day period, a different data set was collected from another 3-day period or the subject was excluded from data collection. Demographic data (eg, gender, height, and body weight) and injury-related information (eg, duration, level, completeness, and severity of injury) were also collected according to the International Standards for Neurological Classification of Spinal Cord Injury.[20]

Analyses

IBM SPSS Statistics 20 was used for all analyses.[21] Descriptive statistics were used to present demographic and injury-related data as well as both systolic (SBP) and diastolic (DBP) blood pressures and HR. Subjects were categorized into 4 age groups: 0 to 5 years, 6 to 12 years, 13 to 15 years, and 16 to 18 years. Chi-square test was used to measure the distribution of American Spinal Injury Association (ASIA) Impairment Scale (AIS) severities among the age groups and between genders. As we hypothesized that BP and HR would vary in relation to age and level (tetraplegia/paraplegia) or completeness of injury,

Table 1. Characteristics of study population (N=315)

Characteristic	n	% or mean (SD)
Gender, male	186	59.0
Race		
Caucasian	235	74.6
African American	17	5.4
Other	63	20.0
Age, years		12.3 (4.7)
0-5	38	12.1
6-12	96	30.5
13-15	77	24.4
16-18	104	33.0
Age at injury, years		9.5 (6.0)
0-5	113	35.9
6-12	67	21.3
13-15	81	25.7
16-18	54	17.1
Duration, months		37.7 (43.8)
0-3	52	16.5
3.1-6	14	4.4
6.1-12	42	13.3
12.1-24	60	19.0
>24	147	46.7
Etiology		
Motor vehicle	183	58.1
Medical/surgical	53	16.8
Violence	24	7.6
Sports	23	7.3
Falls	26	8.3
Other	6	1.9
Level of injury, paraplegia	207	65.7
Completeness of injury, complete	196	62.2
AIS severity		
C1-4 ABC	37	11.7
C5-8 ABC	61	19.4
T1-S5 ABC	195	61.9
AIS D	22	7.0

Note: AIS = American Spinal Injury Association (ASIA) Impairment Scale.

this distribution within our study population was determined to observe how it would influence the results. Distribution of the age groups in both genders was also determined. One-way analysis of variance (ANOVA) and Bonferroni post hoc analysis were used to compare BP and HR values among age groups. Comparison among AIS severity groups (C1-4 ABC, C5-8 ABC, T1-S5 ABC, AIS D) was conducted to determine differences in BP and HR in relation to severity and neurologic level of injury. For comparisons of BP and HR in relation to gender, level of injury (paraplegia vs tetraplegia), completeness of injury, and diurnal differences, *t* tests were used. Morning and afternoon BP and HR measurements were further compared within each of the AIS severity groups to determine a relationship between neurologic level of injury and diurnal variation. Associations between BP and HR with age, BMI, and duration of injury were determined with Pearson correlations. Linear multiple regression analyses were conducted to determine significant predictors of changes in BP and HR; the independent variables used were those found to be significant factors associated with BP and HR differences in the univariate analyses.

Results

Data were collected from 315 subjects admitted from January 2003 to February 2012 who met the inclusionary criteria. Demographic and injury-related information are presented in **Table 1**. Mean age was 12.3 (4.7) years with the distribution among the age groups showing a lower proportion of the 0 to 5 year age group. The distribution of AIS severity among the 4 age groups and between genders is presented in **Table 2**. T1-S5 ABC was the most frequent severity in all age groups, whereas the 16 to 18 year age group had the highest frequency of cervical level injuries (ie, C1-4 ABC and C5-8 ABC). Distribution of AIS severities between genders revealed similar frequencies of males and females for C1-4 ABC, but males had higher frequencies in all other AIS severity groups. The distribution of age groups was similar in both genders ($\chi^2 = 2.084$; df = 3; $P = .555$).

Comparison of cardiovascular measurements among the age groups revealed a stepwise increase in BP and a stepwise decrease in HR with each successive age group (**Table 3**). SBP was significantly higher in males, while HR was higher in females. Among the AIS severity groups, the C1-4 ABC group was found to have lower SBP compared to the other groups; however, significant intergroup differences did not emerge with post hoc analyses. SBP was significantly lower in complete injury compared to incomplete and showed a tendency to be higher in those with paraplegia compared to tetraplegia.

Both BP and HR were significantly higher in the afternoon (p.m.) compared to the morning

Table 2. Distribution of ASIA Impairment Scale (AIS) severity among age groups and genders (N=315)

Age group and gender			AIS severity group C1-4 ABC	C5-8 ABC	T1-S5 ABC	AIS D	Total
Age group[a]							
	0-5	n	8	6	22	2	38
		% within age	21.1	15.8	57.9	5.3	100
		% within AIS	21.6	9.8	11.3	9.1	12.1
	6-12	n	9	6	68	13	96
		% within age	9.4	6.2	70.8	13.5	100
		% within AIS	24.3	9.8	34.9	59.1	30.5
	13-15	n	8	14	51	4	77
		% within age	10.4	18.2	66.2	5.2	100
		% within AIS	21.6	23.0	26.2	18.2	24.4
	16-18	n	12	35	54	3	104
		% within age	11.5	33.7	51.9	2.9	100
		% within AIS	32.4	57.4	27.7	13.6	33.0
	Total	n	37	61	195	22	315
		% within age	11.7	19.4	61.9	7.0	100
		% within AIS	100	100	100	100	100
Gender[b]							
	Male	n	18	39	109	20	186
		% within gender	9.7	21.0	58.6	10.8	100
		% within AIS	48.6	63.9	55.9	90.9	59.0
	Female	n	19	22	86	2	129
		% within gender	14.7	17.1	66.7	1.6	100
		% within AIS	51.4	36.1	44.1	9.1	41.0
		n	37	61	195	22	315
	Total	% within gender	11.7	19.4	61.9	7.0	100
		% within AIS	100	100	100	100	100

Note: ASIA = American Spinal Injury Association.

[a]$\chi^2 = 35.354$; df = 9, $P < .001$.

[b]$\chi^2 = 12.293$; df = 3, $P = .006$.

(a.m.), reflecting physiologic diurnal variation. Comparison of morning and afternoon measurements within each of the AIS severity groups, however, revealed no diurnal difference in those with cervical level injuries (C1-4 ABC and C5-8 ABC) (**Table 4**). Significant diurnal differences in SBP, DBP, and HR were observed for those in the T1-S5 ABC group, and significant diurnal differences in SBP and HR were observed for those in the AIS D group. Current age, age at injury, and BMI were positively correlated to both SBP and DBP, whereas these same factors displayed significant negative associations in relation to HR (**Table 5**). No significant correlation was found between duration of injury and the cardiovascular measures. Since the proportion of those with paraplegia was significantly higher than those with tetraplegia, the association with duration of injury was assessed separately for tetraplegia and paraplegia; no significant correlation was observed in either group between duration of injury and BP or HR. Regression models indicated that both age and BMI independently predict changes in SBP and DBP, with AIS also a predictor of SBP (**Table 6**). The only predictive factor for HR was age.

Discussion

To our knowledge, this is the first study to report normative BP and HR measurements as a function of age in children and adolescents with SCI. In our study population, BP was higher and HR lower in

Table 3. Comparison of blood pressure and heart rate with demographic and injury-related factors

Demographics		**SBP (mm Hg)**	**DBP (mm Hg)**	**HR (beats/min)**
Age group	0-5	98.6 (6.7)	57.9 (6.5)	105.3 (22.6)
	6-12	103.8 (7.0)*	58.6 (5.1)	90.2 (9.6)
	13-15	109.9 (8.9)*†	61.6 (5.3)*†	87.4 (11.6)*
	16-18	111.8 (9.4)*†	62.4 (5.2)*†	81.6 (11.5)*†
	P[a]	**<.0001**	**<.0001**	**<.0001**
Gender	Male	109.5 (9.5)	60.5 (5.7)	87.1 (16.1)
	Female	104.0 (8.3)	60.5 (5.6)	90.6 (12.1)
	P[b]	**<.0001**	.937	**.038**
Severity	C1-4 ABC	103.3 (10.8)	59.4 (6.5)	89.7 (16.5)
	C5-8 ABC	107.2 (9.8)	61.3 (6.8)	86.8 (21.6)
	T1-S5 ABC	108.0 (9.1)	60.5 (5.2)	88.6 (11.9)
	AIS D	107.8 (7.0)	60.5 (5.0)	89.5 (9.8)
	P[a]	**.049**	.477	.744
Completeness	Complete	106.3 (9.0)	60.1 (5.2)	87.7 (12.1)
	Incomplete	109.1 (9.9)	61.2 (6.2)	89.4 (17.8)
	P[b]	**.010**	.081	.333
Level	Tetraplegia	105.8 (10.1)	60.7 (6.6)	88.4 (19.6)
	Paraplegia	108.0 (9.0)	60.4 (5.1)	88.5 (11.4)
	P[b]	.052	.701	.941
Diurnal	Morning	105.8 (9.9)	59.7 (6.3)	86.2 (19.0)
	Afternoon	108.8 (10.8)	61.5 (6.7)	90.7 (14.1)
	P[c]	**<.0001**	**<.0001**	**<.0001**

Note: Values given are mean (SD). Bold indicates significance.

[a] *P* values for one-way analysis of variance. [b] *P* values for independent *t* test. [c] *P* values for paired *t* test.

*Significant difference compared to the 0-5 year age group, Bonferroni α <.025.

†Significant difference compared to the 6-12 year age group, Bonferroni α <.025.

Table 4. Diurnal differences of blood pressure and heart rate within AIS severity groups

Severity		**SBP (mm Hg)**		**DBP (mm Hg)**		**HR (beats/min)**	
		a.m.	**p.m.**	**a.m.**	**p.m.**	**a.m.**	**p.m.**
C1-4 ABC		102.5 (11.5)	104.1 (12.7)	59.0 (7.6)	59.7 (7.8)	90.4 (18.3)	89.1 (17.5)
	P	.391		.597		.556	
C5-8 ABC		107.7 (10.8)	107.9 (9.9)	61.7 (6.7)	61.8 (7.7)	87.4 (23.4)	85.3 (14.5)
	P	.817		.899		.575	
T1-S5 ABC		105.9 (9.6)	109.8 (10.5)	59.2 (5.9)	61.7 (6.2)	85.3 (12.7)	92.1 (13.2)
	P	**<.001**		**<.001**		**<.001**	
AIS D		105.0 (6.2)	110.4 (10.7)	59.2 (5.0)	61.5 (6.7)	83.2 (11.2)	96.1 (10.3)
	P	**.018**		.088		**<.001**	

Note: Values given are mean (SD). *P* values are for paired *t* test. Bold indicates significance. AIS = American Spinal Injury Association (ASIA) Impairment Scale; DBP = diastolic blood pressure; SBP = systolic blood pressure; HR = heart rate.

Table 5. Correlations of cardiovascular measures with demographic and injury-related factors

	Age	Age at injury	BMI	Duration of injury	Duration tetra[a]	Duration para[b]
SBP	.492*	.359*	.493*	.012	-.162	.060
DBP	.340*	.257*	.272*	.019	.004	.034
HR	-.491*	-.407*	-.150*	.076	.154	.036

Note: Values given are Pearson correlation coefficient. BMI = body mass index; DBP = diastolic blood pressure; SBP = systolic blood pressure; HR = heart rate.

[a] Correlation with duration in tetraplegia (n=108).

[b] Correlation with duration in paraplegia (n=207).

*$P < .05$.

Table 6. Regression models for predictors of change in cardiovascular measures

Predictors		B	SE	*t*	*P*	95% CI	R^2
SBP	Age	.703	.106	6.648	<.001	.495 to .912	.347
	BMI	.490	.080	4.045	<.001	.333 to .646	
	AIS	1.801	.589	3.059	.002	.642 to 2.960	
DBP	Age	.323	.072	4.469	<.001	.181 to .466	.126
	BMI	.130	.054	2.390	.017	.023 to .237	
HR	Age	-1.625	.177	-9.164	<.001	-1.974 to -1.276	.238

Note: AIS = American Spinal Injury Association (ASIA) Impairment Scale; BMI = body mass index; DBP = diastolic blood pressure; SBP = systolic blood pressure; HR = heart rate.

each successively older age group. These findings confirm our hypothesis that increasing BP and decreasing HR are associated with increasing age and are similar to the physiologic changes observed in normal development in which cardiovascular measures approach adult levels in adolescence.[9,10] Direct comparisons with able-bodied peers, however, could not be made as the mean baseline BP values in our SCI population were collected by age group, whereas the normograms reported for typically developing children present BP values according to specific chronologic age and height percentile.

Comparison among AIS severity groups revealed that those with higher cervical injury (C1-4 ABC) had lower mean SBP compared to those with lower cervical and thoracolumbar level injuries. Similarly, regression analysis revealed that AIS severity, which is stratified according to completeness and neurological level of injury, independently predicts changes in SBP. These findings reflect the impact of reduced sympathetic activity below the level of injury at the cervical spinal segments as a result of loss of connectivity with the thoracolumbar sympathetic chain.

Correlation analyses revealed positive associations between BP and BMI, age, and age at injury, and regression models indicated that age and BMI independently predict changes in BP and HR. Although the positive correlation between BP and BMI is similar to that of typically developing children,[9] this is of particular concern in the SCI population. The decrease in physical activity following SCI increases the risk for body composition changes (namely, increased adiposity) and decreases resting metabolic rate, which can lead to increased risk of complications such as impaired glucose tolerance, hyperlipidemia, and cardiovascular disease.[22,23] It has also been reported that the BMI in children with SCI underestimates the actual body fat content, and thus the normal cutoff values for obesity have low sensitivity in detecting obesity and underestimate the incidence of obesity in this population.[23,24] These clinical implications warrant close monitoring of BMI and body composition changes in youth with SCI during their maturation and encouragement of active lifestyles to decrease the risk of future metabolic and cardiovascular disorders.

Gender differences in BP and HR of our study subjects displayed similar patterns as those of the general pediatric population, with males exhibiting higher SBP and females having higher HR. The gender differences in BP and HR in typically developing youth have been attributed to differences in size and body composition, level of physical activity, and hormonal effects on the autonomic nervous system.[9,25,26] Although specific tests for body composition and hormone levels were not conducted in this study sample, in general we found that the physiologic and developmental cardiovascular changes in youth with SCI occur similar to their typically developing peers in regard to age, gender, and BMI.

Loss of diurnal variation of BP in individuals with SCI has been observed and ascribed to the decrease in sympathetic control, especially in those with complete cervical level injuries.[1,6,27] In our study population, a diurnal variation similar to the physiologic was observed when all individuals were included, with lower BP and HR in early morning and higher measurements in the late afternoon. In comparing morning and afternoon measurements within each AIS severity group, however, diurnal differences were absent in the C1-4 ABC and C5-8 ABC groups, while significant diurnal differences were present in both the T1-S5 ABC and AIS D groups, again reflecting the influence of sympathetic activity below the level of injury on diurnal variation in BP. Our findings mirror those found in studies of adult SCI circadian differences; both BP and HR variations were slight in persons with tetraplegia as opposed to the normal variation observed in persons with paraplegia, and those with tetraplegia were found to have lower levels of plasma norepinephrine compared to the control participants and those with paraplegia.[6,27]

The pathophysiology of AD in SCI has been attributed to the development over time of peripheral adrenoreceptor hypersensitivity and restoration of sympathetic ganglia following the initial injury.[1,4] Based on this theory, we hypothesized that baseline BP will increase with increasing duration of injury; however, there was no significant association between BP and duration of injury in our study population. The significance of this finding may be limited due to the fact that the majority of our subjects were studied at a later time point after sustaining injuries (80% had injury duration of 6 months or greater). As changes in BP are expected to be less in those with paraplegia due to the preservation of some sympathetic activity,[6,27] the effect of injury duration on BP in our study population may have been skewed by the higher proportion of individuals with paraplegia (66%). No significant associations were found, however, when correlations between duration and BP were determined separately for persons with tetraplegia. Prospective longitudinal analyses with a larger number of subjects stratified according to age and level and severity of injury are needed to determine the effect of duration on changes in cardiovascular measures.

There are several limitations to this study. As this was a retrospective review, it was not possible to ensure a consistent method of obtaining BP and HR measurements, such as patient position (supine vs sitting; with vs without back or foot support), cuff placement, BP machine, and time of measurement. To reduce potential errors of inconsistency resulting from such factors, data collected from 3 consecutive days were recorded only at specific times for both morning and afternoon, which we determined to be times the subject would have been at rest prior to obtaining BP readings. Medical notes made during the days that data were collected were also reviewed to ensure the patient was in stable condition. Another limitation was the insufficient number of subjects in each age group; this did not allow stratification of the subjects in respect to different levels of injury, severity of injury, or duration of injury to determine how these factors would affect BP and HR in each age group. Furthermore, although AIS classification was determined as best as possible from neurologic examination records, delineation of AIS classification in the younger 0 to 5 year age group was difficult due to the unreliability in their responses to motor and sensory testing.[28] Cardiovascular measures can also be affected by the presence of SCI-related conditions (eg, pain, spasticity, neurogenic bladder/bowel), the application of compression garments (eg, abdominal binders, stockings) and any medications and psychological issues, but these were not assessed. Future research should include studies to determine whether and how such SCI-related factors might affect cardiovascular function outcomes in the pediatric SCI population. Additionally, further controlled prospective studies on baseline BP and HR as a function of age and BMI and stratified by level, severity, and duration of injury will provide valuable information for managing cardiovascular complications as well as monitoring changes during maturation into adulthood.

Conclusions

In youth with SCI, baseline BP increases and HR decreases with increasing age and BMI. Awareness of baseline BP and HR is essential for the recognition and management of cardiovascular complications, such as OH and AD in SCI, especially for persons presenting with atypical signs and symptoms.

Acknowledgments

This study was supported by the Advanced Rehabilitation Research Training (ARRT) grant H133P100008 from the National Institute on Disability and Rehabilitation Research (NIDDR), US Department of Education, Washington, DC.

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